How ambitious can we be in contributing to the world's energy needs with bioenergy, wind, solar and storage?

Targets and road maps from Workshop on Sustainable Energies, Technical University of Denmark, 14 – 15 January 2009

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Risø DTU
National Laboratory for Sustainable Energy

Editor: Henrik Bindslev

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As part of the DTU Climate Change Technologies Programme, DTU arranged a series of workshops and conferences on climate change technology focusing on assessment of and adaptation to climate changes as well as on mitigation of greenhouse gasses (GHG). Each workshop targeted a specific technology problem area. The Workshop on Sustainable Energies took place at DTU 14 – 15 January 2009. The workshop defined a number of ambitious but realistic targets and described roadmaps to reach these targets. This report presents the targets and road maps.

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Preface

Henrik Bindslev, Risø DTU

About 13 % of the world's primary energy currently comes from renewable energy sources, most from traditional biomass, 2 % from hydropower and just over 1 % from modern renewable energies, primarily wind. It is a great industrial, technical and political challenge to increase the contribution from these modern renewable energy technologies. EU has the ambition to raise the contribution from renewables to 20 % in 2020, Denmark the ambition to raise it to 30 % in 2025. There is broad consensus among climate scientists that to keep the risk of dangerous climate changes to a reasonable level energy production in the world must be virtually free of green house gas emissions well before the end of this century. How far can we go, what stands in the way and what should the leading actors do? That is what the workshop addressed.

AIM

The aim of the workshop, which was part of the DTU Climate Change Technologies programme (www.dtu.dk/climate), was to define a number of ambitious but realistic targets and describe roadmaps to reach these targets. The roadmaps will be given as input to the UN Climate Change Conference, COP 15, and as inspiration for action to meet climate challenges. The roadmaps describe contributions and commitments needed from industry, research and policy.

The workshop addressed the challenges for increasing the contribution from wind power, bioenergy and solar energy. The aim was to identify initiatives that can accelerate development and deployment of these technologies. This includes energy storage and implementation and interaction of storage technologies with the overall energy system.

FORMAT

In four parallel sessions, visions, opportunities and challenges for each topic were discussed by invited speakers and the participants coming from research, industry and policy makers. The themes for the four parallel sessions were: Wind energy, Bioenergy, Solar energy and Energy storage. On the back of these discussions, working groups were charged with identifying targets and road maps which are presented in this report.

All targets and roadmaps were discussed in the parallel sessions and selected targets and roadmaps from each session were discussed by a panel in a final joint session, with interventions from the audience and the proponents. The presentations of targets and roadmaps given here take the discussions into account, but are ultimately the views of the named proponents behind each set of target and roadmap. The thinking behind this format is that the most rapid progress is achieved through competition of ideas carried by dedicated proponents, proponents who cannot be required to agree on the relative merits of different technologies and ideas. Thus, this report is not a consensus document but a snapshot of the market place of ideas for the new energy technologies, which hopefully will make our energy consumption sustainable in the not too distant future.

Bioenergy

Introduction (Klaus Breddam and Kim Pilegaard, Risø DTU)

At present, the most efficient way to convert dry biomass into energy is by combustion in power plants to generate electricity and heating for houses. Development of new systems for gasification of biomass may further improve the efficiency, in particular when efficient distribution of heat only can be secured by a network of small plants. Biomass with large water content cannot be utilized in this way, but efficient systems have been developed which allow the conversion of such biomass into biogas which then can be used in a power plant as described above. These technologies are already in use and further improvements can be expected.

Electricity generated from biomass can be distributed over long distances and used in a variety of ways. For transport of people and goods, electricity can be used in trains and for charging batteries in small cars with a limited range. Otherwise the transport area represents a challenge since efficient, energy-dense and abundant biological substitutes for gasoline and diesel presently are not available.

The liquid biofuels produced today fall into two categories, based on their origin, notably carbohydrate or fat. Bioethanol can be produced from carbohydrates by fermentation of for instance sugar cane or maize, in the latter case only subsequent to enzymatic depolymerisation of the starch. With today's oil prices bioethanol cannot compete with gasoline and it appears that the process of producing has been optimized to the extent possible. However, the biggest problem lies in the fact that such production of fuel will compete with the production of food and feed, thus creating the agricultural challenge to meet both needs and simultaneously prevent environmental damages.

Carbohydrates for fermentation can be obtained from non-food sources like straw and wood, but at present, the cost of producing "second generation" bioethanol from cellulose is very high. The challenge is to reduce costs of production through development of simple and low-cost production methods.

Triglycerides can be converted into biodiesel or diesel by means of chemical technologies already established within the chemical industry. The challenge here is to produce triglycerides in amounts that really matter when the quantity of the World need of transportation fuel is taken into consideration. The origin of the present production of biodiesel is animal waste and plants with high oil content. This production cannot be increased significantly – again due to the competition with food supply.

Microbial algae, with very high oil content, produced in parts of the world that cannot be farmed, might be a solution, but only if a series of technological challenges are met. Microbial algae provide very efficient photosynthesis, but methods for producing the algal biomass in large scale at a relevant price are still lacking. Within this area a dedicated research effort is needed.

Target 1: Intensify use of Biogas Gasification for Efficient Energy production

1.1 Target description

The target is to extend the utilization of biomass based combined heat and power production by applying biomass gasification technologies.

Biomass is a scarce resource that must be used in a highly efficient, economical and flexible way. Biomass gasification offers a highly efficient solution in small, medium and large scale. Gasification combines maximized power production with maximized total efficiency through combined heat and power production or by combined cooling and power production coupled with extensive district heating and cooling.

Extending the use of district heating based on combined heat and power production holds a big potential for CO_2 and energy savings in itself. By utilizing biomass as fuel we can achieve significant CO_2 saving. In an energy efficient society, 30-50 % of the EU energy consumption could be produced from biomass by 2030.

1.2 Challenges

1.2.1 Market and Industry

Markets for bioenergy technologies are emerging in some countries like Germany and Italy. The bioenergy market needs to be extended to the whole of the EU and industry needs to embrace these new opportunities.

1.2.2 Research and Education

The universities must educate more engineers with knowledge about bioenergy technologies to cover the industry's demand.

1.2.3 Policy

It must be made clear to policy makers that bioenergy is a significant and reliable base for a 100 % renewable energy system, and that bioenergy's flexibility complements the fluctuating production of energy from other renewable technologies.

1.3 Actions and recommendations

Action on implementation of bioenergy needs to be taken now. The technologies are ready for demonstration and implementation, but substantial financial investments are required. There is no doubt that the current recession provides a golden opportunity for investments in high efficient bioenergy technologies that will be profitable and benefit the world for generations.

1.3.1 Market and Industry

There is a need to:

1. Design and erect full scale demonstration plants based on combination of existing bioenergy technologies
2. Develop and demonstrate new bioenergy technologies

1.3.2 Research and Education

3. Establish closer cooperation between research, industry, financial sector and policy makers
4. Optimize systems and integrate different bioenergy technologies
5. Set more focus on thermal conversion of biomass in education.

1.3.3 Policy

6. Further increase taxation of fossil fuels in the industrialized countries in order to create a competitive market for new renewable energy technologies
7. Promote the substitution of natural gas fired heating with district heating from combined heat and power production.
8. Implement efficient instruments and mechanisms for the promotion and implementation of bioenergy solutions in the developing countries.

1.4 Road map

Actions	2008-2010	2010-2015	2015-2020
Policy			
Market /industry	1, 2	2	
Research/education	3, 4, 5	4, 5	
Policy	6, 7, 8	X	

1.5 Proponents

- Jesper Ahrenfeldt, Risø DTU, Denmark (chairman, rapporteur)
- Suresh Babu, TERI Technologies Limited, India
- Peder Stoholm, Danish Fluid bed Technologies, Denmark
- Wolfgang Stelte, Risø DTU, Denmark
- Ralph-Matthias Schoth, DANISCO Sugar A/S, Denmark
- Ulrik Birk Henriksen, Risø DTU, Denmark
- John Bøgild Hansen, Haldor Topsøe A/S, Denmark

- Jonas Valdimarsson, NIRAS, Demark
- Mads Frederik Hovmand, Copenhagen University, Denmark
- Marie Kimming, Swedish University of Agriculture, Sweden

Target 2: Improve economics of 2G bioethanol to replace 10 % of gasoline by 2020

2.1 Target description

There is a significant research and development effort going on globally to develop more economical second generation (2G) bioethanol processes that will improve bioethanol production efficiencies and allow the use of alternative feedstocks instead of starch and sugar based ones.

The suggested target is to replace 10% of gasoline with bioethanol in 2020 with reduction of green house gases (GHG) of at least 80%.

To reach these targets the following sub tasks should be addressed:

1. **Improvement of economics of 2G bioethanol production**
2. **Prepare detailed carbon and energy balance calculations for 2G bioethanol production**

2.2 Challenges

2.2.1 Market and Industry

- We need to open up markets for new products: 2G bioethanol and other value added products
- This would imply that we will operate on a saturated market in the transition period.
- We need to provide sufficient investments in 2nd generation technologies that require high capital cost at startup for large scale production.

2.2.2 Research and Education

- Increased research in the usage of C5 sugars can significantly improve the yield and cost position of existing bioethanol producers. C5 sugars in bioethanol fermentation are becoming increasingly important as there is pressure on bioethanol margins.
- Further development of the processes for utilization of C5 polymers and sugars for new biomaterials, chemicals and pharmaceuticals (value added products) is a new and promising research area.
- Lignin utilization for fuel and valued added byproducts like lignin-rich fermentation residues can potentially generate enough energy for bioethanol production. Lignins can be used as raw materials for other value added product in a biorefinery concept.
- More research should be focused on processing of raw materials, which is the major cost of bioethanol production including drying process.

2.2.3 Policy

- There is a need for ambitious political initiatives in support of 2G bioethanol production
- A mandatory quota of 10% use of each biofuel can stimulate the production

2.3 Actions and recommendations

The Working Group recommends, in order to boost the 2G bioethanol in Europe:

- Fiscal incentives should be differentiated between 1st and 2nd generation biofuels, preferably based on CO_2 credits.
- European public policies should be uniform and establish, as mandatory, equal 10% targets both for biodiesel and bioethanol.
- Preparations for a regulatory framework at European level should be initiated immediately with the goal to introduce large scale production of E85 blends.

2.3.1 Market and Industry

1. Assistance to farmers cooperatives to prepare them for the opportunities
2. Introduction of flexible-fuel vehicles (FFV) that can run on biofuels
3. Establishing of a distribution network system for bioethanol

2.3.2 Research and Education

4. Research in ways to reduce enzyme costs in biofuels production is important
5. Improve C5 utilization in biofuel production
6. Finding new lignin utilizations for high value added products

2.3.3 Policy

7. Risk reduction of biofuel pilot plant and startup companies
8. Introduction of differentiated tax incentives for use of biofuels
9. Provide sufficient venture capital for investments in precompetitive startsups
10. Support of biofuels demonstration plants
11. Provide incentive for public private co-financing of biofuel pilot plants
12. Establish a separated quota for obligatory use of each biofuel type

2.4 Road map

Actions	2010-2015	2016-2025	2026-2035
Industry / market			
1. Assistance to farmers	X	X	
2. Introduction of FFV	X	X	X
3. Network system for bioethanol	X	X	X
Research	X	X	X
4. Improved C5 utilizations	X		
5. Reduce enzyme cost	X		
6. Improved lignin utilization	X	X	
Policy			
7. Risk reduction	X	X	
8. Differentiated tax inc.	X	X	
9. Capital support	X	X	
10. Demo plants	X		
11. Co-financing	X	X	
12. Separated quota for each biofuel	X	X	

2.5 Proponents

- Børge Holm Christensen, Biosystemer ApS, Denmark (Chairman)
- Anne Belinda Thomsen, Risø DTU, Denmark (rapporteur)
- Jack Saddler, UBC, Canada
- Francisco Girio, INETI, Portugal
- Charles Nielsen, DONG Energy, Denmark
- Nina Eriksen, Novozymes, Denmark
- Thomas Mathiasen, TM-Innovation, Denmark
- Chresten Meulengracht, EthanoLease I/S, Denmark
- Zsófia Kádár, Risø DTU, Denmark

Target 3: 40 PJ biogas based energy should be produced and effectively used in 2020

3.1 Target description

- By 2020 biogas should cover 20 PJ produced from manure and 20 PJ produced from other organic waste and energy crops.
- Public transport and trucks should used 25 % (10 PJ) of the biogas produced in diesel motors, dual fuel motors and later in dedicated engines. These 10 PJ would cover 5 % of the energy used in road transport and account for 10 % since it is 2nd generation bioenergy. Where it is possible we should use raw biogas and upgrade the rest. The amount of substituted diesel is important to reach the EU target.
- This scenario requires a well functioning biogas market that includes green certificate trade.

3.2 Challenges

3.2.1 Market and industry

The following challenges should be met by industry and market operators:

- Building biogas plants and operate them in a professional way (e.g. owned by farmers)
- The transportation sector should develop a market for bioenergy through fleets of vehicles with focus on public transport.
- Establish infrastructure for biogas distribution in the transportation sector

3.2.2 Research

The biorefinery technology is well developed, but research should focus on:

- Introduction of new waste and energy crops for bioprocessing
- Up and down streams separation; optimization and manure management

3.2.3 Policy

- It is important to set political focus on production of biofuels and to release the bonds to power production and the substitution of biogas.
- Taxation of biogas production should be reduced
- No extra tax should be imposed for upgrading cars to biogas
- A national plan for placing biogas plants should be adopted and it should be forbidden to spread untreated manure

3.3 Actions and recommendations

It is recommended to look into other ways of using biogas than heating e.g. production of methanol and usage in fuels cells. Co-digestion is important therefore farmers should establish manure-based biogas plants and not only focus on e.g. energy crops

Action 1: Release the biogas from the binding to power production– now

Action 2: Facilitate tax-free biogas in the natural gas grid – now

Action 3: Remove tax on the extra costs for upgrading cars to biogas – soon

Action 4: Plan legislation for biogas plant placement – soon

Action 5: Forbid spreading of untreated manure in the fields– soon

Action 6: Research in manure management with focus on N and especially P (soon)

Action 7: Fuel tax in the transportation should be lowered to increase the used biogas – now

3.4 Road map

Actions	2008-2010	2010-2015	2015-2020
Policy			
Action 1	X		
Action 2	X		
Action 3		X	
Action 4		X	
Action 5		X	
Action 7	X		
Research			
Action 6	X	X	X

3.5 Proponents

- Knud Boesgaard, Energinet.dk, Denmark (Chairman)
- Jens Ejbye Schmidt, Risø DTU, Denmark (Rapporteur)
- Yuliya Voytenko, Central European University, Hungary
- Zeyuan Zhang, Roskilde University, Denmark
- Per B Hansen, Danisco Sugar, Denmark
- Jørgen Henningsen, EPC, Denmark
- Piotr Oleskowicz-Popiol, Risø DTU, Denmark
- Frank Rosager, Xergi, Denmark
- Tyge Kjær, Roskilde University, Denmark
- Mikael Kau, Energy City Frederikshavn, Denmark

Target 4: Sustainability standards for internationally traded biomass.

4.1 Target description

All biomass for food, feed, fuel and fibre which is internationally traded should comply with standards for sustainability

- By biomass we include primary biomass (agri- and silvicultural production) as well as secondary biomass (post-consumer waste like industrial waste, household waste, manure).
- By sustainability we include similar possibilities for future generations, future productivity to match the world population, conservation of resources.
- By standards we include regulations at country level and certification at farm level.

The sustainability of biomass for energy has been widely debated and questioned in recent years. The present target is a necessary step towards achieving sustainable global production of food, feed fuel and fibre. Specifically, the sustainability of biofuels can not been evaluated in isolation, biofuels must be seen as part of the global biological production system.

4.2 Challenges

4.2.1 Market and industry

- Structure production of biomass to meet the criteria for sustainability
- Adopt systems to track and trace products to source
- Meet the risk that certification sets limits to innovation in the production due to focus on reaching the certification requirements
- Prioritize between different uses of biomass

4.2.2 Research

- Define criteria and indicators for sustainability by experiments and theory to be able to assess sustainability of any biomass production
- Develop a system to track and trace products to source
- Develop methodologies to monitor net land use changes as a response to any given policy
- Describe, integrate and validate criteria for sustainable biomass
- Ensure that scientists value their research in relation to sustainability
- Reduce uncertainties in the sustainability assessment by means of experiments
- Communicate uncertainties in the sustainability assessment to policy makers

4.2.3 Policy

- On a national and international level the following political issues need to be addressed:
- Establish national and international criterea for sustainable biomass production and introduce compulsory regulations/standards

- Integrate criteria for sustainability of biomass produced for different sectors, e.g. bioenergy, forestr
- Introduce EU operational and transparent regulations which imply that all EU products are certifiable
- Make political priorities between different uses of biomass

4.3 Actions and recommendations

Recommendations:
Secondary biomass (waste) should be the main source for bioenergy production. Primary biomass should only be used when sufficient attention is paid to all sustainability aspects e.g. in case of rural development or poverty reduction strategies. Sustainability issues should be at focus in education at all levels

Policy Actions:

1. International standards should be established on definitions and criteria for sustainability (e.g. EU, WTO, UN, FAO, IEA, UNEP, OECD). Such agreements should be operational and transparent for market actors
2. EU regulations shall comply with these standards
3. It is important to keep up the momentum of the RES directive on biofuels (Directive on the promotion of the use of energy from renewable sources, COM(2008)0019).

Research Actions:

4. Sustainable production should get an ever increasing role on the global research agenda
5. Funding bodies should include sustainability as evaluation criteria

Industry Actions:

6. Farmers associations and industrial organizations should develop sustainable production schemes
7. Certificate of sustainable biomass production is established to help investors in supporting sustainable production

4.4 Road map

All actions as described under 4.3 need to start during 2010-2015, and are anticipated to continue beyond that period.

4.5 Proponents

- Cecilia Sundberg, Department of Energy and Technology, Swedish University of Agricultural Sciences, Sweden (Chairperson)
- Hanne Østergård, Biosystems Division, Risø DTU, Denmark (Rapporteur)
- Erik Steen Jensen, Biosystems Division, Risø DTU, Denmark
- Peder Jensen, EEA, Copenhagen, Denmark (Only first day)
- Edward Smeets, Copernicus Institute, Utrecht University, Netherlands (Only first day)

Target 5: To make biorefineries practical so as to contribute to future bioenergy needs.

5.1 Target description

The overall concept of biorefinery has been discussed for some decades. However, in the sense of using multiple raw materials to produce a diverse range of bioproducts, biorefineries have generally not yet been commercially realised at an industrial scale.

The following targets should be addressed:

- **Boosting agricultural yields** to ensure sufficient and reliable biomass production to meet the needs of efficient biorefinery operation while also addressing future global food demand.
- **Optimising the incoming biomass stream** as a resource for a wide range of bioproducts, thereby replacing crude oil.
- **Establishing a large-scale biorefinery** to prove the concept and to open the platform for the full potential of biomass exploitation.
- **Developing a flexible bioproduct portfolio** which will meet the global market demands.

5.2 Challenges

5.2.1 Market and industry

Industry should

- Work for public acceptance of GMO crops
- Select between many technological options
- Address increasing competition and IPR challenges

5.2.2 Research

There is a need to intensify research in:

- Separation of clean fractions
- Best utilisation of each fraction – closed loop principle
- Long-term process stability

5.2.3 Policy

- Mechanisms with reduced control and bureaucracy
- Political and fiscal support of biorefinery development and demonstration
- Public education in renewable energy

5.2.4 Actions and recommendations

It is mandatory to establish a new biorefinery organisation and a procedure to ensure that biorefineries are developed with urgency and at suitable speed. This organization must select a limited number of actions and seek political and financial support. New initiatives and their potential must be evaluated by international expert groups with members from both industry and research.

The following actions are recommended to be taken:

Action 1: Define an appropriate organisation and procedure to realise and maximise opportunities from the biorefinery technology in a suitable timeframe.

Action 2: Establish a construction of a large-scale biorefinery by 2012 and operate it continuously for two years.

Action 3: Explore and develop improved crop yields targeting specific biorefinery needs with a secure supply of defined and homogeneous biomass.

Action 4: Identify a diverse range of bioproducts.

Action 5: Select the best large-scale biorefinery configurations and build it at multiple locations.

Action 6: Ensure public acceptance of Bioenergy production

5.3 Road map

Actions	2010-15	2016-25	2026-2035
Industry/market			
Action 1	x		
Action 2	x		
Action 3		x	x
Action 5		x	
Research			
Action 1	x		
Action 2	x		
Action 3	x	x	x
Action 4	x	x	x
Policy			
Action 1	x		
Action 6	x	x	

5.4 Proponents

- Hans Lilholt, Risø DTU (Chairman), Denmark
- David Plackett, Risø DTU (Rapporteur), Denmark
- John Jensen, Danisco Sugar A/S, Denmark
- Nadja Schultz, Risø DTU, Denmark
- Natanya Hansen, Risø DTU, Denmark
- Zsuzsa Sarossy, Risø DTU, Denmark
- Claus Felby, University of Copenhagen, Denmark
- Henning Jørgensen, University of Copenhagen, Denmark

Wind energy

Introduction (Flemming Rasmussen and Peter Hjuler Jensen, Risø DTU)

Successful development collaboration between research, industry, authorities and the public, has resulted in a wind energy penetration of 1.3% of the electricity on a global level. The installed wind energy capacity is doubled every three years, and has been for the last 25 years. So far only one percent of the global wind capacity is installed offshore. In an ambitious, but realistic scenario, 25% of the world's electricity consumption will be covered by wind energy by 2050. Research in new technology, wind mapping and siting as well as wind integration has in this perspective an enormous potential.

Wind energy technology has gone through an enormous development during the past 25 years. It has evolved from low technology to present day high technology, resembling, and in some areas approaching the level of aircraft technology. During that period, turbine sizes have increased by a factor of 100 from approximately 50 kW for the first commercial turbines to now 5 MW for the largest. This upscaling has been driven and accompanied by technology and cost optimization.

As the technology develops to represent a realistic and important contribution to the energy supply of the world, so does the technological perspectives. The challenges are so immense that we are very far from a point of "diminishing return" of investments in research.
In the beginning smaller turbines were built on mass produced components from other fields of application than wind power. The increase in size to multi-Mega Watt turbines has resulted in specialized components for each turbine model. The turbines do not use standard existing technology, instead they are technology drivers.

Targets for wind power should be more ambitious than what they are today. As described in the advanced scenario of the report by GWEC/DLR and in the Risø DTU report to the IEA (both issued 2008), a global wind power penetration of 25 % by 2050 is achievable. These scenarios are based on growth rates of 27 % in 2008, falling to 22 % in 2010, to 12 % by 2020 and 5 % by 2030. These scenarios are realistic, and long-term planning now should be based on these growth rates.
To reach the target of establishing wind energy as the backbone of a secure global energy supply the following issues need to be addressed:

- Technology optimization covering the turbine, the infrastructure and the energy systems integration.
- Various sub-sectors such as wind turbine manufacturers and offshore operators should be more closely integrated.
- Establishing a long-term stable global policy including environmental, financial, infrastructural, research and educational issues.
- Exploitation of synergies between wind energy and other applications

Target 6: Global wind potentials – more reliable wind predictions - An accurate estimate of the wind climatological characteristics at any given point on Earth

6.1 Target description

The aim is to create a high quality, high resolution database of wind resources and wind energy related data on a global scale.

A global mapping of wind results in:
- Acceleration of the global deployment of wind
- Optimization of the use of wind
- Gold digging (discover unexplored wind resources)
- Better sitting
- More certain wind projects and thereby more valuable wind projects

Focus of the re-analysis on wind speed accuracy is needed to reduce the uncertainty of modelling

6.2 Challenges

6.2.1 Market and Industry

- Create consensus and acceptance of the method of wind mapping

6.2.2 Research and Education

- Get the right organization
- Build a global organization under WMO. Include the right stakeholders (WMO, IPCC, ECMWF, NOA etc). Further integration of the wind energy community with the meteorologist and climate change communities by a technical subcommittee representing wind energy
- Develop methods and models (Multi scale models)
- Assure robustness against climate change
- Downscaling issues going from Meso-scale to Micro-scale
- Develop and improve numerical models that cover different levels of complexities (multi scale physics).

6.2.3 Policy

- Acceptance of the task and creation of the necessary funding.
- Include the requirement of this initiative in the appropriate policies on the regional and national level
- Willingness of the appropriate body to give access to the necessary data.

– Mobilize the right organizations and build a global organization under WMO. Include the right stakeholders (WMO, IPCC, ECMWF, NOA etc) and accept the aim of the task

6.3 Actions and recommendations

Action 1: Create a consortium that carries out the initiative in the global community (2009)
Action 2: Create a Global overview based on existing knowledge and data (2010)
Action 3: Collect data and agree on the methodology (2011)
Action 4: Create the first version of the Numerical Wind Atlas of the entire World (2012)
Action 5: Develop numerical tools that cover different levels of complexity (multi-scale physics) (from 2010 to 2035)
Action 6: Develop coherent policies to facilitate access to meteorological data for wind energy purposes at international level.
Action 7: Encourage international organizations (WMO, ECMWF) in their R&D plans to take into account wind energy requirements in the field of meteorology.

6.4 Road Map

Actions	2010-15	2016-25	2026-2035
Industry/market			
Action 1	X		
Research			
Action 2	X		
Action 3	X		
Action 4	X		
Action 5	X	X	X
Policy			
Action 6	X		
Action 7	X	X	

6.5 Proponents

- Ignacio Marti, CENER, Spain (Chairman)
- Hans E. Jørgensen, Risø DTU, Denmark (Rapporteur)
- Lars Landberg, Garrad Hassan, Denmark
- Li Jun Feng, Energy Research Institute, NDRC, China
- Jens Nørkær Sørensen, DTU Mechanical Engineering, Denmark
- Erik Lundtang Petersen, Risø DTU, Denmark
- Søren E. Larsen, Risø DTU, Denmark
- Poul Hummelshøj, Risø DTU, Denmark

Target 7: Large-scale penetration of wind energy to cover 25 % of the global electricity consumption.

7.1 Target description

Targets for wind power should be more ambitious than what they are today. A wind power penetration of 25% by 2050, as described in the advanced scenario of the report by GWEC/DLR and in the Risø DTU report to the IEA (both issued 2008) is achievable. These scenarios are based on growth rates of 27 % in 2008, falling to 22 % in 2010, to 12 % by 2020 and 5 % by 2030. These scenarios are realistic, and long-term planning now should be based on these growth rates.

7.2 Challenges

Background challenges:

There are several challenges regarding the wind power development that need to be addressed:

- Public acceptance of deployment on land is an issue, even if opinion polls indicate an improvement in acceptance; new policies may influence availability of land and increase the need to go offshore;
- Demonstrate to politicians and authorities that wind power is economically feasible and affordable, including the necessary infrastructure;
- Grid capacity is a limiting factor for wind power expansion, so reinforcements and development are needed;
- Existing electricity market design is not appropriate for wind power;
- At present solutions are found on national level; but regional cooperation is required;
- Recruitment of sufficient and qualified staff is lacking behind

7.2.1 Market and industry

Electricity markets and power industry must:

- Facilitate further developments in wind power
- Develop intelligent power systems – generation, transmission and use
- Expand and develop wind power, interconnectors and power system industries
- Secure sufficient recruitment of highly skilled staff

7.2.2 Research and education

Research and education must address the following topics:

- Technology for intelligent and flexible power systems and integration (power, transport, heating/cooling)
- Mapping of regional wind power behaviour – variability and predictability
- New electricity market design and model for energy and grid management
- Technology improvements aiming at cost reductions pr. KW

- Understanding interconnection between costs, value and affordability
- Reliable scenarios for developments in integration of more wind energy

7.2.3 Policy

Important political challenges include:

- Long-term national and regional planning for wind power is needed in the form of binding wind targets and coordinated spatial and grid planning.
- National and regional agreements on infrastructure investments must be established
- The Transmission System Operators (TSOs) should be obliged to cooperate more
- The electricity markets should be designed to facilitate increasing exploitation of wind energy, including internalisation of external costs
- Integration of the power, transport and heating sectors would be very important

7.3 Actions and recommendations

Long-term national and regional planning for wind power with binding wind targets and commitments are urgently needed, including agreements to facilitate initiation of necessary infrastructure investments.

The following actions should be addressed:

7.3.1 Market and industry

1 New electricity market design and model to facilitate wind power
2 Transmission System Operators (TSO) implementation of grid development including identification of bottle necks and initiate grid reinforcements and interconnectors
3 Transmission System Operators (TSO) cooperation in energy and grid management
4 Gradually expand common electricity markets to cover entire regions

7.3.2 Research and Education

5 Demonstration of large-scale integration of power and transport – electrical vehicles in power systems
6 Global initiatives on education – more power engineers, bring new technologies into education, develop appropriate curricula for wind
More research items see 7.2.2

7.3.3 Policy

7 Long-term national and regional planning for wind power with binding wind targets and commitments
8 Coordination of spatial wind planning hand-in-hand with grid planning
9 Political initiative on regional planning and agreements to facilitate necessary infrastructure investments

7.4 Road map

Actions	2010-2015	2016-2025	2026-2035
Industry/market			
Action 1	x		
Action 2	x	x	x
Action 3	x	x	x
Action 4	x	x	
Research			
Action 5	x	x	
Action 6	x	x	x
Policy			
Action 7	x		
Action 8	x		
Action 9	x		

7.5 Proponents

- Jens Carsten Hansen, Risø DTU, Denmark (Chairman)
- Troels Friis Pedersen, Risø DTU, Denmark (Rapporteur)
- Nicolaos A. Cutululis, Risø DTU, Denmark
- Poul-Erik Morthorst, Risø DTU, Denmark
- Eric Birksten, Swedish Wind Energy, Sweden
- Niels E. Busch, Busch & Partners, Denmark
- Stine Poulsen, Danish Energy Agency, Denmark
- Rebekka Falk, Danish Energy Agency, Denmark
- Samira Viswanathan, IIIEE, Lund University, Sweden
- Tomas Kåberger, Swedish Energy Agency, Sweden
- Ayla Uslu, European Environment Agency, Denmark
- Ernest Troth, White Door, Inc., USA
- Sabrina Azaiez, Denmark
- Hannele Holttinen, VTT, Finland
- Bertel Lohmann, Techconsult, Denmark
- Jeppe Bjerg, IEA, France
- Lise Backer, Vestas, Denmark
- Nicolas Fichaux, EWEA, Belgium

Target 8: Develop wind energy as the backbone of a secure global energy supply.

8.1 Target description

To reach the target of establishing wind energy as the backbone of a secure global energy supply the following issues need to be addressed:

- Technology optimization covering the turbine, the infrastructure and the energy systems integration.
- Various subsectors such as wind turbine manufacturers and offshore operators should be more closely integrated.
- Establishing a long-term stable global policy including environmental, financial, infrastructural, research and educational issue. Such a policy will enable industries to carry out strategic investments in specific wind energy technologies such as dedicated wind energy offshore infrastructure like vessels. In line with this the whole supply chain for large-scale wind turbine production should be addressed.
- Exploitation of synergies between wind energy and other applications such as electrical vehicles (V2G), ocean energy, offshore harbours, solar energy, pumped storage in combination with hydropower plants.

8.2 Challenges

8.2.1 Market and industry

It is important to address the following challenges:

- Optimize manufacturing, commissioning, transport installation, O&M methods, decommissioning for large-scale operations in particular for offshore applications.
- Integration of sub design packages into integral packages is urgently needed. Integration methods should take into account that various subsectors of the industry have their own design cultures. Industries are willing to include modules which describe technologies that are new to their own technical universe, into their own tools, but they are seldom willing to replace their own tools by a whole new set. Examples: the offshore designers use their own verified tools and add wind turbine modules and vice versa for the wind turbine designers.
- Development of standards fitting new applications, novel technical concepts and operations as well as the continuing updating of existing standards.
- Supply chain issues
    - Two categories of supply chain constraints exist: Physical constraints and critical mass of market volume. Strategies to avoid supply chain limitations include:
        - Component standardization (common platforms) (industry and R&D prioritization)

        - Service provider standardization (policy, R&D including regular standards development procedures)
        - Development of manufacturing facilities for large-scale wind system (industrial policy)

8.3 Research and education

Research challenges:

- Offshore and onshore technology issues are distinctly different, but applications remain equally important.
- Offshore applications are the driving force of long-term research, but results are likely very useful for the improvement of small and medium size turbines which are generally for onshore deployment.
- Up-scaling, improving reliability and reducing costs over lifetime are the key objectives while improving and developing new technologies for future large-scale wind energy applications.
    - Examples:
        - advanced control (distributed control)
        - direct driven generator systems
        - new materials with a higher strength to mass ratio and to be manufactured at low cost
        - new generators (permanent magnet generators, superconducting generators)
        - control systems for further dynamic load reduction
        - monitoring of wind turbine condition for estimation of the remaining lifetime of wind turbine
- Feedback of operational data from industry to R&D is needed to improve the operational performance of wind turbine systems
- Common understanding of what skills are needed in the wind industry
- Improving mechanisms to better incorporate the industry's R&D needs into academic and public R&D bodies. (This is also a policy issue.)
- Develop dedicated offshore technologies with high priority

8.4 Policy

The biggest political challenge is to put the required policy measures in place IN TIME. Lead times for certain measures should be the basis for planning policy measures. (T: approximate lead time)

- Realize an electrical infrastructure including storage capabilities (T > 10 years)
- Stable policy for exploitation of wind energy (T > 3 years)
- Education in wind energy technology (T > 5 years)

Further challenges:

- How to focus the R&D efforts on the sector's needs?
- Develop with high priority policy frame works for accelerated deployment of offshore wind power plants.

A long-term policy as a condition for large-scale investments in technology should include:

- Harmonization of planning (spatial planning, safety, environmental protection)

- Financial incentives (long-term stability, transparency, stimulation of industrial activities in the whole sector), e.g. feed-in tariffs and government taking a joint venture interest in strategic projects
- Creating an infrastructure (international grid (in modular way), storage)
- Establish universal standards for BSc and MSc education in wind energy

8.5 Actions and recommendations

Governments should co-finance large-scale pilot plans in order to reduce risks for private investors and to implement systematic monitoring and evaluation programmes to stimulate learning processes and to secure efficient reduction of costs. An interesting option could be if governments own as joint venture a limited number of wind turbines for testing. The ownership could be transferred to the wind farm owner at a later stage.

Create a global think tank that addresses strategic studies: international off shore policy, needs for data banks (wind energy hub for data such as wind, wave, shipping, safety issues, morphology, ecology), large scale infrastructural planning.

There is a political need for establishing universal standards for education, dedicated training courses, adaptation of the university curricula etc.

8.5.1 Market and industry

Action 1: Promote the development of the standards on critical issues
Action 2: Public access to and feedback cycles of data from wind farm operators to research and R&D
Action 3: Promote up-scaling, improvement of reliability and development of new technologies
Action 4: Develop dedicated off-shore technologies

8.5.2 Research and education

Action 5: Promote the development of the standards on critical issues
Action 6: Open access and feedback cycles of data from wind farm operators to research and R&D bodies
Action 7: Implement long-term research schemes for sustainable energy

8.5.3 Policy

Action 8: Establish stable and long-term policy for development of sustainable energy
Action 9: Provide political incentives to coordinate and initiate research activities that are based on technology needs addresses by industry and public research (European Academy of Wind Energy – an initiative on global level like a UN research programme)
Action 10: Harmonization of regulation and permitting procedures.
Action 11: Promote infrastructure developments, including grid and storage capabilities.
Action 12: Develop procedures for government joint venture interest in strategic projects

8.6 Road map

Actions	2010-2015	2016-2025	2026-2035
Industry/market			
Action 1	X		
Action 2	X	X	X
Action 3	X	X	X
Action 4	X		
Research			
Action 5	X		
Action 6	X	X	
Action 7	X	X	
Policy			
Action 8	X		
Action 9	X	X	
Action 10	X	X	X
Action 11	X		
Action 12	X	X	

8.7 Proponents

- Jos Beurskens, ECN - Wind Energy, The Netherlands (Chairman)
- Thomas Buhl, Risø DTU – Wind Energy Division, Denmark (Rapporteur)
- David Quarton, Garrad Hassan & Partners Ltd, UK
- Peter Hauge Madsen, Risø DTU – Wind Energy Division, Denmark
- Nicolas Fichaux, EWEA, Belgium
- Jørgen Lemming, Risø DTU – Wind Energy Division, Denmark
- Djoko Andric, Department of Policy and Communication, DTU, Denmark
- Asger Abrahamsen, Risø DTU, Denmark
- Flemming Rasmussen, Risø DTU – Wind Energy Division, Denmark
- David Boye, DNV, Denmark

Solar Energy

Introduction (Peter Sommer-Larsen, Risø DTU and Simon Furbo, DTU Civil Engineering)

Solar energy might become a major component of future sustainable energy supply in the form of solar thermal heating, photovoltaics (PV) and concentrating solar power (CSP). Solar thermal heating has potential to cover up to 50% of the heating and cooling demand in Europe by 2050. Similar potential is found for electricity production for cities in Europe. Installation of solar energy technologies displays exceptional growth rates in these years. It is not clear if this pace can continue and generally it will require industry to bring down production costs.

Solar thermal systems comprise Solar domestic hot water (SDHW) systems - Solar combi systems for heating of buildings and domestic hot water supply - Solar heating plants for heating a whole town or a part of a town by means of a district heating system - Solar cooling systems - Solar heating systems for desalination and purification of water - Air collectors for dehumidification of buildings.

Today simple financial payback times of solar heating systems are 5-15 years, and merely by making technological improvements they are expected to be halved. At present, worldwide, the solar heating market grows by more than 30% a year, and the growth is expected to continue. Globally a capacity of 128 GW_{th} was installed in 2006. The European Solar Thermal Technology Platform (ESTTP) has set the target of covering 50% of the heating and cooling demand in Europe by 2050.

PV systems comprise Grid connected building mounted or building integrated (BIPV) installations – Other grid connected systems (i.e. highway sound barriers) - Grid-connected centralised power stations or solar farms - Off-grid residential and non-residential systems – power supply for consumer electronics.

Economics of PV is often measured against grid parity: the point, where the price of solar cell power becomes equal to the average consumer price for electricity. Obviously, grid parity depends on the region and it has been reached in sunny regions. The European Photovoltaic Industry Association (EPIA) expects grid parity to be reached all over Europe in 2020. Incentive schemes in Europe resulted in a 110% growth of the photovoltaic market in 2008 – corresponding to 6 GW new installations. Globally, the installed capacity is now 14 GW_{el}. EPIA targets PV coverage of 20% of Europe's electricity demand by 2030.

Concentrating Solar Power comprise centralised power plants. The total installed capacity is still small – approx. 1 GW_{el} – but a number of plants are under construction and the European Solar Thermal Electricity Association (ESTELA) and the Desertec Foundation expects up to 15% of Europe's electricity demand to be covered by CSP.

Theoretically, solar energy is the largest renewable energy source: The earth receives more energy from the sun in just one hour than mankind uses in a whole year. Solar cells, solar thermal heating systems, and concentrating solar power plants are well proven and mature technologies. It calls for a paradigm shift in our energy supply - and action now - to harvest the free energy from the sun. In particular:

- Deployment on a large scale must be planned and started now
- Education of all actors in the field must be increased: Engineers, developers, installers, salesmen etc.
- Research with the aim to further develop economically attractive solar energy systems must be increased
- A long term stable global policy with the aim to reach the ambitious target must be established.

Target 9: Transforming our urban societies to solar cities.

Solar cities will produce 50 % of the regional – or even national – electricity demand by 2050. With focus on OECD towards 2050, BRIC towards 2075 and the whole world towards 2100.

9.1 Target description

Two thirds of the global energy production is consumed in cities today and the share may even grow to three quarters in 2050.[1] Photovoltaic technology has the potential to transform cities into electricity producing entities, and it is the only renewable electricity source that is easily integrated in urban environments.

A solar city is to a great extent powered by solar energy – in particular electricity produced by photovoltaics (PV). In a solar city, PV is in particular integrated in buildings and deployed on up to 25 % of rooftops and free spaces. The concept of a solar city at the same time implies a sustainable society where energy saving goes hand in hand with building-integrated power production.

The target is that, in the OECD countries, ***solar cities produce 50 % of the regional – or even national – electricity demand by 2050***. The target is expanded to the BRIC[2] countries in 2075 and the rest of the world by 2100.

The concept of solar cities should be seen as an important step towards our long-term vision – a sustainable world powered nearly 100 % by solar energy, wind energy and bioenergy by 2100. This target is an answer to how ambitious we can be on photovoltaics. As described in detail under Challenges below, solar cities is an investment in a future energy supply. The target is technically feasible, but its realization depends upon our willingness to take this investment.

9.2 Challenges

9.2.1 Market and industry

The challenges involved in transforming our cities from virtually no installed PV to cities where approximately one quarter of rooftops and free spaces is covered by photovoltaics are immense both from a technical and a sociological viewpoint. This section outlines some of these challenges and at the same time hopefully convincingly describes why the ambitious target is realistic. We should:

1. *Reduce production costs in order to achieve grid parity for private households by 2020, for industry by 2030 and for bulk electricity production by 2040.*
   Grid parity is the point where the price of solar cell power becomes equal to the average consumer price of electricity. Geographically unevenly distributed solar resources, different costs of systems, installation and grid connection make the financial payback time of a solar system vary from region to region. Hence the industrial challenge is more precisely to lower production prices to a level where grid parity is reached even at the latitudes of Northern Europe.[3]
   A production cost of 1 €/Wp is generally accepted as the premise for grid parity.

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[1] IEA, World Energy Outlook 2007
[2] Brasil, Republic of South Africa, India, China
[3] EPIA Sept. 2008

2. *Continue the learning curve.*
Recently, the announced increase in production capacity in the PV industry has been assessed and the planned production capacity was summed to more than 40 GW by 2012.[4] If this number holds, it has two implications: 1) the penetration of solar power in our energy mix takes a leap forward in the coming decade. 2) The production and retail price of solar cells will decline. PV has followed a learning curve where the price was reduced by 20 % each time the production volume doubled.[5]
Hence the challenge addresses the continued strive for reducing manufacturing costs in the PV industry, and sets the target to a learning rate of 20 %.

3. *Reduce energy payback time for PV systems.*
Closely connected to a decrease in financial payback time for a PV system is the energy payback time (EPT). Strong reductions in materials use (i.e. reducing Si-wafer thickness and loss of Silicon in the wire-cutting of wafers) have a direct effect on both costs and energy use for solar cell production. A system, however, also includes other components - module assembly, balance-of-system components. These components need to follow the cell down in cost and resource use.
The energy payback time is crucial to the net CO_2 reduction gained from PV systems during scale-up of system installations. For a system placed under optimal conditions, grid parity is already reached today as demonstrated by a recent 10 MW thin film PV installation in Nevada. For such systems the energy payback time is approximately 2 years. With an annual increase in installed capacity of 40 %, there could be virtually no net CO_2 reduction from PV systems. Every second year, the installed capacity doubles and the energy needed to produce these new PV systems precisely equals the energy generated by the already installed PV systems. The energy from the PV systems is used to maintain the installation rate.
In the scenario discussed here, we assume an installation increase rate of 40 % per year up to the point where grid parity is reached in most of OECD (around 2020) and afterwards a 20 % increase per year. Based on an EPT learning rate of 10 %, an estimate is that by 2020 the EPT is reduced to 1 year and only half of the total energy produced is used for maintaining the installation rate.

4. *Develop a stable electricity grid in a distributed production system.*
Introducing PV in a massive amount is part of electrification of our society. It requires much better control of the grid and a more extended transmission system than today. One possibility is to create a network of transmission lines throughout a region like Europe and to divide our grid into robust cells – where the fluctuating electricity demand is balanced by the sources and where the intermittent power sources supplement each others. PV is well suited here because production occurs during the day where demand is high. The PV production is often high when wind is low and vice versa. PV systems in general tend to improve power quality.

5. *Develop financial instruments/mechanisms as the basis for incentives.*
As described under *policy challenges*, there is a need to maintain current incentive mechanisms in the build-up period until 2020. These include feed-in tariffs and net-metering. In a longer perspective, it will be beneficial to change some of the incentives into stable financial incentives like “soft loans” where, e.g., an interest bonus is given to investments in renewables. Financial mechanisms will to a greater extent allow the financial world, i.e. energy service companies (ESCOs), to dedicate investments to PV installations. Investment costs for PV are high and there exists a psychological barrier for many private households to embark upon these long-term investments.

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[4] *PV Status Report 2008*, Ed. Arnulf Jäger-Waldau, European Commission, DG Joint Research Centre (2008)
[5] Nearly all studies state module or system retail prices and not true production prices due to unavailability of data. In a period since 2006, the system price only decreased slightly as the module price went up [*Trends in photovoltaic applications*, IEA-PVPS T1-17:2008]. 2008 figures and 2009 expectations indicate a marked decrease in module and system price.

6. *Avoid bottlenecks throughout the whole value chain – from raw materials to trained personnel. Continuing the learning curve – 40 GW production capacity by 2012, 200 GW by 2020 and then an annual growth rate well below 20 %.*
   According to IEA, the electricity demand in the OECD countries will be of the size 12,000 TWh in 2030.[6] Assuming this figure also holds in 2050, the solar city target requires an installed capacity of 6000 GW by 2050 or approximately 200 GW installed per year from 2020 to 2050.

9.2.2 Research and education

Fundamental development of human resources is essential at all levels to implement PV – policy makers, architects, installers and users. Worldwide more than 10 million professionals need to be educated.
Long-term research supporting technological breakthrough is a precondition for continued learning curve development beyond 2020. Progress for current single and polycrystalline solar cells and thin film solar cells will support the scale-up of production capacity and cost decreases inherently underlying the learning curve up to 2020. At that point, new technological breakthroughs are most likely needed in order to maintain a learning rate. A number of third-generation PV technologies hold promises for ultra low cost solar cells. These technologies, i.e. polymer solar cells and concentrating high-efficient PV, are currently being developed and are ready for niche markets (small-scale electronics, space use ect.). However, for bulk power production and market penetration after 2020, there is a need in the coming decade for a number of important research breakthroughs and demonstrations on a progressive scale.

9.2.3 Policy and incentives

<u>Urban planning, building regulation and servitudes</u> must be adapted to promote PV installation. It is obvious that building regulations and servitudes on existing buildings may hinder PV deployment. Hence there is a need for general regulations allowing a change of servitudes in promotion of PV installations. Harmonization is a particularly painful challenge – but the benefits of harmonized standards for renewables in buildings are enormous. This holds for both building and electrical regulations, i.e. the electrical interface to the grid. A starting point should be harmonization at the EU and later at the OECD level.

We should develop and implement the right mix of incentives that supports the target of solar cities:

- <u>Feed-in tariffs</u> have proven to be an outstanding incentive during the build-up of the PV industry. The incentive should be faded out at a pace that still allows the ambitious plans in this roadmap to be fulfilled. It is a challenge to determine which temporary and permanent incentives are best suited.
- <u>Net-metering principle</u> is a candidate as a permanent incentive for building integrated PV in private households – but at a scale that allows for the target. PV has the highest investment cost of commercially deployed renewable energy sources today. Although the investment costs will decrease, it is a challenge to develop and implement financial instruments - like soft loans - suited for PV deployment.
  <u>Deployment of PV in solar farms</u> increases faster than building-integrated PV today. Most likely, solar farms become competitive with other renewable power plant sources by 2012 and the proper incentives need to be developed, i.e. power purchase agreements in competition with off-shore wind farms.

9.3 <u>Actions and recommendations</u>

Solar cities are synonymous with worldwide penetration of PV as a renewable energy technology and the sun as the primary energy source. The deployment of PV in a scale where up to 25 % of available rooftops and free spaces are used is a tremendous challenge and an investment – an investment in a sustainable future. The

[6] IEA, *World Energy Outlook 2008*

ultimate goal must be to deploy as much solar energy as is needed to sustain a balance between energy production and demand. Today's technology will take us quite a bit of the way, but new technological breakthroughs are still needed. The third generations of photovoltaics, which are at the research and early demonstration/application level today, hold definite promises for these breakthroughs.

There is a need for awareness in policy, education and research that the PV industry in only four years may grow to a size similar to the wind turbine industry today. It calls for a readiness to build up educational activities, knowledge at all levels, regulations and public acceptance. Penetration of PV will occur worldwide – also in northern Europe. PV will need temporary incentives in order to develop from its current state into a fundamental energy technology – followed by permanent incentives in a stable market.

The industry and the market must secure a steady build-up of PV systems production capacity, supporting market and financial mechanisms, and continued innovations in building integration. Research and education must make PV a focus area: more than 10 million professionals at all levels need to be trained, and continued research and demonstration of new technologies are required. The political frames must be long-term, steady and reliable - supporting and harmonizing the necessary incentives and regulations. Finally, the public acceptance must be raised, and awareness of the technological feasibility of solar energy in a sustainable future must be created.

The roadmap establishes OECD as the frontrunner for solar cities. This is logical because the infrastructure necessary for the deployment of PV is in place. The major challenge for fulfilling the roadmap in OECD is to sustain the growth in production capacity and market. In 2008 China became the largest solar cell producer and the penetration of PV in the BRIC countries may face primary infrastructure challenges.

9.3.1 Market and Industry

Action 1.1: Call for continued policy support, i.e. ***feed-in tariffs*** until grid parity for private households is reached and then a change to permanent incentives. Supply the data needed as a background for political decisions. Work on consensus that allows for harmonization.

Action 1.2: Call for ***industrial operational freedom***; creating the optimal conditions for the PV industry to grow by establishing human resource development, raw materials access, energy access and technological research and development support.

Action 1.3: ***Accelerate energy conservation measures.*** The target of 50 % PV power is realistic when coupled to a slowly growing electricity demand per capita.

Action 1.4: ***Develop the robust and smart grid*** that will be capable of handling large-scale deployment of PV.

Action 1.5: ***Develop the financial market and instrument -*** i.e. ESCOs and soft loans – useful both in the transition phase and in a stable market.

9.3.2 Research and education

Action 2.1: ***Education*** at all levels to establish and maintain a chain of knowledge from decision makers to implementers and end users capable of supporting the massive investments and workload associated with the transition to solar cities.

Action 2.2: By establishing ***PV as a focus area in energy research*** and education through long-term commitment from R&D funding, a human resource base can be established. Solar energy must become a corner stone of education at all levels.

9.3.3 Policy

The overall actions needed in policy are focused on harmonization of incentives, regulations and interface to the grid to secure a transparent industry framework.

Action 3.1: ***International collaboration*** through, e.g., IRENA and harmonization measures will be the key to provide unified understanding and a qualitative development of PV as an electricity source in cities.

Action 3.2: ***Regulation and urban planning of the building environment*** must be reassessed to comply with the needs of the solar city concept.

Action 3.3: Develop and maintain ***economical incentives for renewable energy*** power plants, i.e. brown field development must be sought to attract entrepreneurs and investors to further develop the PV industry.

Action 3.4: A foreseeable obligation is to ***harmonize regulation for electrical grid interface*** at an OECD level. This is needed to secure the foundation of the optimal management of the smart grid.

9.4 Road map

The road map for PV contains many layers that work in combination in order to reach integration of PV in the global energy production. The road map consists of a number of actions over time, which together conclude a change from fossil fuel dependency to PV dependent electricity production by 2100. That leaves us 91 years or a little less than the same time it took us to reach peak “oil”.
The road map is illustrated by table 1 and shows an immense need for full-scale implementation of actions now and continuous maintenance and development of needed framework in policy, education, market and industry.

Action/period	**2010-2020**	**S**	**2020-2050**	**2050-2075**	**2075-2100**
Market /industry	**1.1, 1.2, 1.3, 1.4, 1.5**	**CALEUP**	**OECD**	**BRIC**	**ROW**
Education	**2.1, 2.2**				
Policy	**3.1, 3.2, 3.3,3.4**				

9.5 Proponents

- Peter Ahm, PA Energy, Denmark (Chairman)
- Peder Vejsig Pedersen, Cenergia Energy Consultants, Denmark
- Ivan Katic, Danish Technological Institute, Denmark
- Hanne Lauritzen, Danish Technological Institute, Denmark
- Torben Damgaard Nielsen, Risø DTU, Denmark (Rapporteur)
- Peter Sommer-Larsen, Risø DTU, Denmark

Target 10: Educating in the use of solar energy at all levels in society.

10.1 Target description

The ambition of solar energy contributing with 10 % of the total electricity demand in the EU by 2020 and by 50 % in the OECD by 2050 requires the concerted action by several factors, one of which being education as dealt with in the following. Even with the appropriate subsidy programmes in place to push for solar thermal and PV, its massive deployment cannot happen at the pace required unless the appropriate knowledge is conveyed to the relevant players in society. Hence education on the possibilities of making solar energy an integral part of our daily life is an urgent and pressing issue. Below we have identified three sub-targets of particular importance.

1. *Raising the awareness of the general public*
   There is an urgent need to increase the awareness at all levels in society concerning the potential of using solar energy in order to reach a more sustainable energy production. Despite national and regional variations, large fractions of the population are still totally unaware that technical standard solutions are marketed. These solutions allow solar energy to become an integral part of the general energy mix, be that in terms of heating or electricity. Among those in society who are in fact aware of solar thermal and PV, only a few feel familiar and at ease with incorporating such techniques into their everyday life. Therefore, an understanding must be conveyed to the general public that solar thermal and PV are indispensable energy sources that should enter on an equal footing with traditional energy sources and eventually replace these.

2. *Educate children/students:*
   Children and students are the end-users of the various solar energy technologies of tomorrow, and some will become professionals working in the field. We envisage that for the coming generations, solar thermal and PV should be considered on an equal footing as conventional energy technologies. Education on solar energy should target children and students as future consumers of solar energy technologies, but should also aim at recruiting people to fill jobs in the complete supply chain required by these technologies.

3. *Educate professionals.*
   An estimated 15-20 million professionals will be needed in various branches of the global supply chain of solar thermal and PV by 2030. To set this number into perspective, it is estimated that at present approximately 300.000 (100.000 in PV and 200.000 in solar thermal)[1,2] professionals are employed in businesses related to solar energy worldwide. Consequently, there is clearly a pressing need to push for education of technical personnel, in particular at the level of technical schools where installers are typically trained.

10.2 Challenges

Challenges relating to target 1: Raising the awareness of the general public

- Massive information campaigns aimed at the general public are expensive – who should provide the financial means required?

- A general increase in the awareness level with regard to solar energy technologies leads nowhere unless specific incentives create a demand in society for adoption of such technologies. To what extent can the most efficient incentives be implemented?

Challenges relating to target 2: Educate children and students:

- Penetrating into the massive information flow to which children and students are subject is very challenging, in particular if the messages are not of central interest to them. Through which channels can children most efficiently be reached with information on why they in particular should adopt solar energy into their lives?

- The topic of solar energy should be made attractive to children and students. This implies more than simply creating an occasional hype, in fact a sustained interest in solar energy must be imprinted in the mindset of a whole generation. How is such a massive and sustained educational task lifted simultaneously at all levels in the educational system?

Challenges relating to target 3: Educate professionals:

- Organizing large-scale training of such a massive number of solar energy professionals is a daunting task. This will require extremely well coordinated action among the different sectors working with solar energy in some way or another, especially considering that these sectors are at present relatively small and not necessarily well connected.

- Despite regional differences, a large majority of professionals in those sectors that potentially could undertake installation of solar thermal and PV are organized in small (family) businesses. Such businesses may be reluctant to start working with technologies with which they have no prior experience. Also, education of existing employees on a voluntary basis may simply pose too large an overhead on such small businesses. Hence, financial instruments need to be found to motivate and organize professionals (installers) within the relevant sectors to adopt and provide (new) solar energy solutions at a rapid pace.

- To facilitate the large-scale implementation of solar thermal and PV at the pace called for, there is an urgent need for the producers to provide installers with a portfolio of standardized solar energy solutions.

- Policy makers must be provided with a better understanding of the regional as well as the global goals that can be reached with solar thermal and PV, and of the relevant time lines required to attain such goals. Hence, how can policy makers be informed as efficiently as possible to allow them to support this emerging market in the best possible way?

10.3 Actions and recommendations

The general recommendation is to stay focused on the educational aspect during a large-scale campaign of implementing solar thermal and solar PV. A failure to do so will result in bottlenecks at various places in the value chain of different technologies with a subsequent slow down of the implementation pace.

Actions needed to reach target 1:

1. Adopt broad information campaigns aimed at the general public using various information channels and media. Ideas could be TV shows (genre Big-Brother with emphasis on zero emission living), events as Solar Olympics or EuroSolar Contests or a single trans-national solar energy day.
2. Set up and subsidize public awareness programmes.
3. Get the media aboard with a commitment to a sustained coverage of the theme.
4. Encourage academia to provide public information.

Actions needed to reach target 2:

5. Governments should provide the means to set up task forces that motivate/go into public schools and educate specifically on the use of solar energy.
6. Student exchange networks focused on the development of solar energy technologies.
7. Make the different solar energy technologies a part of the standard curriculum in technical schools where relevant.

Actions needed to reach target 3:

8. Implementation of specific educational systems targeting solar thermal and PV installers and a corresponding certification systems.

9. Make solar thermal or PV a standard part of the education of installers in the relevant sectors.

Road map necessary to achieve targets 1-3:

Actions	2010-15	2016-25	2026-2035
Target 1			
Action 1	X		
Action 2	X		
Action 3	X		
Action 4	X	X	
Target 2			
Action 5	X	X	
Action 6	X	X	
Action 7	X	X	
Target 3			
Action 8	X	X	
Action 9	X		

10.4 Proponents

- Giovanni Flamand, IMEC, IMEC, Belgium (Chairman)

- Kristian O. Sylvester-Hvid, Risø DTU, Denmark, (Rapporteur)
- Jan Bultman, Energy Research Institute of the Netherlands
- Jesus M. Busturia, CENER, Spain
- Eshagh Yazdanshenas, DTU Byg, Denmark
- Alexander Thuer, AEE Institut for Sustainable Technologies, Austria
- Elsa Andersen, DTU Byg, Denmark
- Peder Bacher, DTU IMM, Denmark
- Martin Aagesen, SunFlake, Denmark

[1]: IEA-PVPS Report T1-17:2008, *Trends in Photovoltaic Applications – Survey report of selected IEA countries between 1992 and 2007*
[2]: Weiss, W; Bergmann, I; Stelzer, R, *Solar Heat Worldwide- Markets and Contribution to the Energy Supply 2006*, A report from AEE - Institute for Sustainable Technologies, A-8200 Gleisdorf, Austria

Target 11: Solar thermal should cover at least 50 % of the heating and cooling demand in Europe by 2050.

11.1 Target description

This target has been set on the assumption that the heating and cooling demand has been reduced by 40 % after applying energy efficiency measures. As the basis for this figure we used a report from ESTTP (European Solar Thermal Technology Platform), www.esttp.org. One of the authors, Jan Olof Dalenbäck, participated in the DTU workshop.

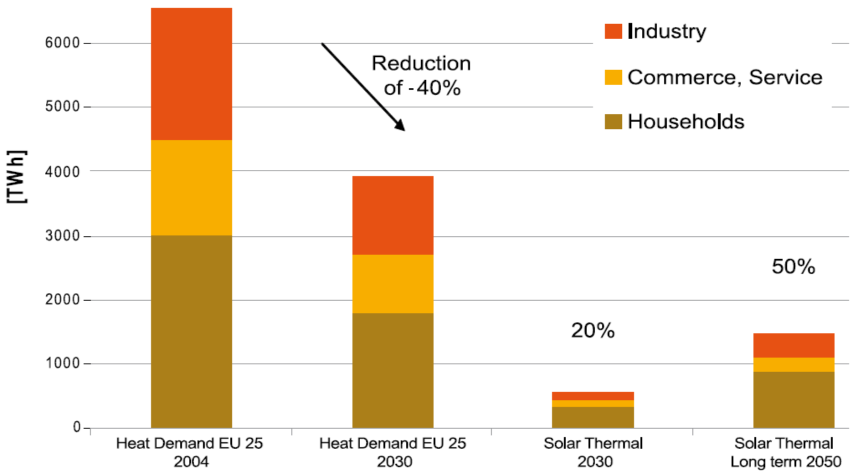

Figure 2: Contribution of solar thermal to EU heat demand by sector, assuming that the total heat demand can be reduced by energy conservation and a 40% increase in efficiency by 2030.
(Source: AEE INTEC, 2008)

Figure 1. Predicted energy demand and solar energy potential.

Another basis for having a high target for solar energy is that "*Every hour, enough solar energy reaches the earth to meet the world's energy demand for a whole year*" (US Dep. of Energy); see Figure 2.

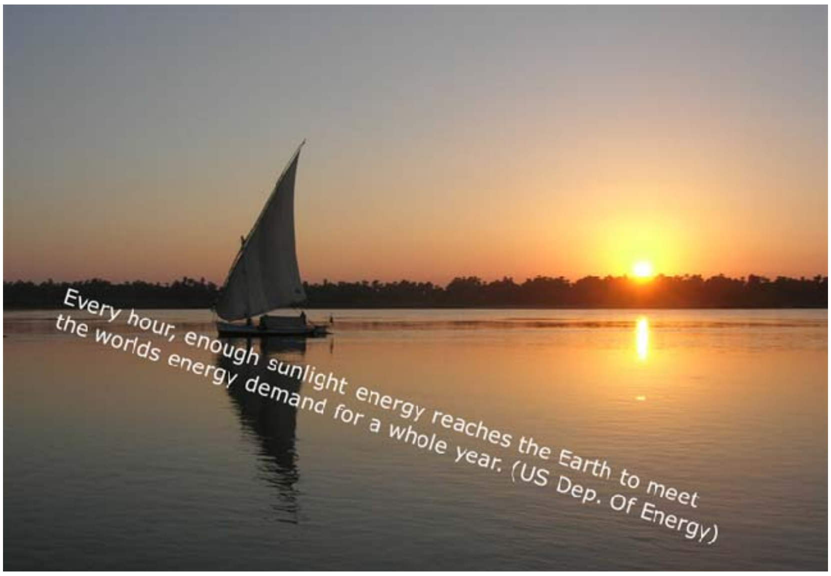

Figure 2. The Solar Energy potential is very large.

The global solar thermal energy production is already very large compared with other renewable energy sources. Only the wind power (and probably also bioenergy, not shown) production is larger; see Figure 3.

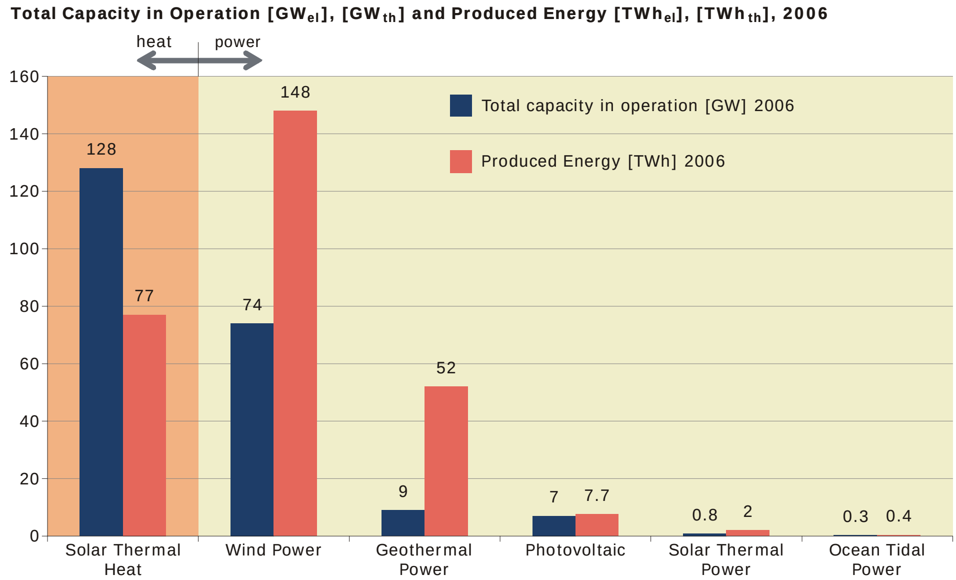

Figure 3. Global energy production from renewables (bioenergy excluded). Source: Presentation by Alexander Thür at the conference.

Another comparison can be made to bioenergy. The Marstal Solar Collector field, shown in figure 4, is connected to the local cogeneration power station and district heating network. The area needed is only 2-3 % of the bioenergy area needed for the same energy production.

Figure 4. Marstal Solar Collector field connected to the local cogeneration power station and district heating network.

11.2 Challenges

11.2.1 Market and industry

- Create awareness and knowledge about the potential for solar thermal energy systems.
- Improve installed system costs/performance ratio of marketed solar thermal systems.

11.2.2 Research and Education

- Meet the research needs of industry: heat storage, smart control, system design, materials.
- Education and training for industry, solar installers, technicians, Master students, PhD students.

11.2.3 Policy

- Stable market support for solar energy
- Visible governmental commitment to install solar thermal on all public buildings.
- Energy policy must be international and include a number of sustanaible energies

11.3 Actions and recommendations

1) Get politicians to adopt that solar thermal should cover at least 50 % of the heating and cooling demand in Europe by 2050.
2) Implementation of solar thermal on all public buildings.

3) Establish solar thermal educational environment at all levels.

4) Develop heat storage technology, with an increased storage capacity of a factor of 8, compared with water within 10 years.

5) Use CO2 quota and tax to support the target of reaching 50 % of the heating and cooling demand in Europe by 2050.

11.4 Road map

Road map to achieve targets:

Actions	2010-15	2016-25	2026-2035
Action 1	X		
Action 2	X	X	X
Action 3	X	X	
Action 4	X	X	X
Action 5	X	X	X

11.5 Proponents

- Jes Donneborg, Arcon Solvarme A/S, Denmark (Chairman)
- Bengt Perers, DTU Byg, Denmark (Rapporteur)
- Niels Lyck, Varmt vand fra solen, Denmark
- Mads Salling-Mortensen, Grundfos A/S, Denmark
- Simon Furbo, DTU Byg, Denmark
- Daniel Trier, DTU, Denmark
- Sten Beltman Jørgensen, Sunmark A/S, Denmark
- Søren Helmersen, SP Group A/S, Denmark
- Klaus Ellehauge, Ellehauge & Kildemoes, Denmark
- Janne Dragsted, DTU, Denmark
- Jan-Olof Dalenbäck, Chalmers University of Technology, Sweden
- Alfred Heller DTIC, DTU, Denmark

Energy storage

Introduction (Allan Schrøder Pedersen and Søren Linderoth, Risø DTU)

In the future sustainable energy system, based on renewable energy sources, a need will inevitably arise for technologies for energy storage. Energy production will not always match the demand for energy and storage facilities must be applied to level out the mismatching fluctuations in production and demand. Furthermore, in such an energy system, where a large share of the primary energy production is presented in the form of electricity from wind mills, solar cells, wave power or similar, new technologies and new fuels will have to be adopted for traction of vehicles for marine, land and air transportation of persons and goods.

In our present energy system fossil fuels - mainly oil products - serve as means for energy stores and they serve very well in terms of economy and storage efficiency. In this sense bio fuels show almost the same attractive properties, whereas it has proven difficult to develop techniques for storage of electric energy, which have efficiencies similar to liquid carbon-based fuels with regard to energy densities (both, gravimetric and volumetric). In addition, storage technologies for electric energy are often expensive and complicated to use and in some cases require use of scarce natural resources.

Major challenges for appropriate energy storage technologies are

- high energy density and low cost
- loss of energy due to heat release in conversion processes
- safety, including safety on-board vehicles
- infrastructural support

The scale of the future need for man-made energy storage capacity is difficult to assess as it depends on many other unknown factors. Examples of such factors, which may influence the need, are the extent of exchange of electricity on a regional level and the ability of energy demand to adapt to variations in production, but others might be mentioned. It is beyond doubt however, that energy storage will be an integrated aspect of fully developed, sustainable energy systems.

Target 12: Chemical energy carriers - storage of electricity for transportation.

Affordable and carbon-neutral synthetic fuels that can satisfy the entire demand of the transportation sector by 2020.

12.1 Target description

Competitive prices in relation to transportation:

- Prices of synthetic fuels should be equivalent to oil prices of 50-100 US$/barrel (~8-16 US$/GJ)
- To reach this target we need low-cost, renewable electricity.

Environmental aspects:

- CO_2 neutrality is a necessity. This requires CO_2 capture from air when using carbon based fuels. Air capture is feasible and the technology is available at the demonstration level. It needs to be at a price well below 100 US$/ton CO_2 (ref. Klaus Lackner, Columbia University, USA).

Potential energy carriers:
We should investigate: H_2, NH_3 and hydrocarbons (methanol, DME, alkanes) as potential energy carriers

12.2 Challenges

12.2.1 Market and industry

Price: Low-cost renewable electricity is necessary if we wish to substitute fossil fuel energy production.

Background information:

	Production price (US$ GJ^{-1})			
	Today, fossil – approximate	Future (2020) renewable - estimates	Cost of storage and distribution	Energy density[c] (MJ/kg, MJ/L)
Electricity	14 (5¢/kWh)	5.5 (2¢/kWh)		
H_2	7	8[a]	High	7, 5 (5 wt%, in hydride or 700 bar)
NH_3	10	11	Medium	23, 14
Methanol/ DME	9	14[b]	Low/Medium	20, 17
Biodiesel	11 (non-fossil)	11	Low	36, 34
Diesel	13	15[b]	Low	39, 35
Gasoline	10	15[b]	Low	41, 33
Batteries	Electricity	Electricity	High	<0.7, <1.5 today

a) Based on a hydrogen production of 8$/GJ equivalent to 46$/barrel of crude oil, based on high-temperature steam electrolysis and electricity price of 2 US¢/kWh (S.H. Jensen et al, *Int. J. Hydrogen Energy*, **32**(15), p. 3253-3257 (2007).
b) Synthetic fuel includes capture of CO_2 from the atmosphere, electrolysis, and fuel synthesis.
c) Includes container.

For a thorough comparison of energy carriers, see Graves & Lackner, forthcoming (2009).

12.2.2 Research

- Further R&D, but not necessarily new inventions, is needed to achieve: incremental improvement – increased lifetime, lowering of prices and high safety level.
- Enabling technologies: storing hydrogen, infrastructure and air capture of CO_2.
- Electrolysis must be significantly improved.
- Demonstration projects and up-scaling of production are necessary –.

12.2.3 Policy

- To really push it – increased taxes on fossil fuels are necessary.
- Price of carbon is also an issue, but carbon is not forbidden, when C is captured.
- We must achieve public acceptance of synthetic fuels. .

12.3 Actions and recommendations'

It is recommended that we use the right fuel for the right purpose (e.g. hydrogen for city buses, liquid fuels for passenger cars).
There is a need for increased funding for R&D and for demonstration of niche markets. Industry should be engaged in niche market applications, including non-energy applications

Action 1: For all fuels we need improvements of electrolysers
Action 2: Synthetic hydrocarbons production need to be coupled with development of CO_2 capture from air (absorbent, infrastructure)
Action 3: Ammonia: safety aspects for handling on vehicle must be developed
Action 4: Hydrogen: hydrogen storage, storage systems and infrastructure must be improved.
Action 5: For all fuels we need system analysis and development

12.4 Road map

Actions	2010-2015	2016-2025	2026-2035
Industry / market			
	Develop niche markets	Commercialization	
		Capture market	
Research			
	Enabling R&D	R&D	
	Demonstration	Demonstration	
Policy			
	Support renewable electricity		
	Taxation of fossil carbon		

12.5 Proponents

- Mogens Mogensen, Risø DTU, Denmark (Chairman)
- Anne Hauch, Risø DTU, Denmark (Rapporteur)
- Debasish Chakraborty, Amminex A/S, Denmark
- Tue Johannessen, Amminex A/S, Denmark
- Tejs Vegge, Risø DTU, Denmark
- Klaus Breddam, Risø DTU, Denmark
- Lars Yde, Hydrogen Innovation and Research Centre, Denmark
- Gunnar Preiß, OHB-System AG, Department "Life Sciences" Germany
- Christopher Graves, Columbia University/Risø DTU, Denmark
- Catherine Lee, Columbia University/Risø DTU, Denmark
- Jason Fish, Colorado School of Mines/Risø DTU, Denmark
- Frank Markert, DTU MAN, Denmark
- Klaus Lackner, Columbia University, USA
- Jesper Krogh Jensen, Baltic Sea Solutions, Denmark
- Jens Christiansen, Teknologisk Institut, Denmark
- Anne Hauch, Risø DTU, Denmark

Target 13: Energy Storage – Batteries for Transport.

A large share of cars sold from 2020 should be electric.
Local target - 20 % of the Danish new vehicles powered by electrics in 2020 = initial attractive market

13.1 Target description

Requirements for batteries should fulfil customers expectations in different applications

1. The applications to consider should be feasible with today's technology
   1. Family car no. 2 – no need for long travel (pendler-car, family-taxi and local shopping)
   2. Heavy – city distribution
   3. Busses – city (19x7)
   4. Family car no.1 – occasional need for long travel with more than 150 km between stops. (Range extender function needed)
   5. Taxi etc. (24x7) (need fast charging or battery swap facility)
   6. Heavy long haul trucks and tourist busses.

2. The expectations for batteries to consider
   1. Batteries for transport should be affordable –
      - Initial cost must only be marginally higher than for conventional cars
      - Life cycle cost must be lowered
   2. Batteries must deliver sufficient range for all daily transport needs in the family or business
   3. Batteries must be reliable – with true "fuel gauge"
3. Battery developments needed to e.g. have 20 % of new vehicles electric by 2020 and 20 % of the Danish vehicle fleet electric by 2025.

13.2 Challenges

13.2.1 Market and Industry

- Establish flexible market models for batteries, e.g. leasing system - isolating risk to customer
- Establish reuse and recycling system – modularity
- Standardisation of batteries: Interface, modularity, allow for new designs
- Back-up plan for batteries
  - second source as minimum.
  - Industrial standard parts (– standards)
  - Encourage a common sub-supplier network

- Establish reliable data for batteries – accountability
- Avoid range anxiety
- Make electric transport attractive
- Establish market scheme involving resale value
- Build up volume production of electric cars in small high tax countries where electric cars can be sold at competitive prices compared to conventional cars.
- Install high speed charge infrastructure along major roads.

13.2.2 Research

- Develop new battery technology – alternative/back-up to Li-ion type
- Ease recycling of storage materials
- Develop batteries with higher energy density and higher power charge capability
- Develop cheaper production processes
- Carry out lifecycle analysis (LCA) of different battery technologies, to recommend the least environmental implication considering different geo-cultural areas
- Develop compact range extender that is silent; e.g. disposable power cell for emergency use only

13.2.3 Policy

- Establish a legislative framework for production and use of electric vehicles
- Develop infrastructure enabling large scale electric transport
  - provide easy charge access
  - develop communication for managing load on distribution grid
- Establish a policy for recycling of batteries and vehicles
- Promote electric transport and conserve bioenergy for periods without wind
- Exempt electric vehicles from environmental restriction zones
- Promote environmental friendly behaviour. Let politicians set good examples

Affordable:

- Create a flexible marked and flexible ownership / leasing system for electric cars
- Develop vehicle to grid functionality in cooperation with leasing companies
- Develop modular battery concepts that allow battery update and reuse

13.3 <u>Actions</u>

Action 1: Establish standardization for interface and battery modules
Action 2: Establish high speed charge infrastructure
Action 3: Develop a reliable market for electric cars and batteries
Action 4: Develop new battery technology – alternative/back-up to Li-ion type
Action 5: Carry out lifecycle analysis (LCA) of different battery technologies
Action 6: Develop infrastructure enabling large scale electric transport
Action 7: Promote electric transport and conserve bioenergy for periods without intermittent renewable power

13.4 Road map

Actions	2010-2015	2016-2025	2026-2035
Standardization interface and battery modules	Standard charging interface developed	Standard battery modules developed	
Industry/market			
High speed charge infrastructure	Prototypes developed	Establish primary along high ways	Establish along primary roads and in cities
Reliable market for electric cars and batteries	Framework proposal for market legislation	Implementation of legislation for batteries and electric cars	
Research			
New battery technology – alternative to /back-up to Li-ion type		New battery types ready for testing	New types of batteries on market
Lifecycle analysis of different battery technologies	Continuous LCA	Continuous LCA	Continuous LCA
Fast high power charge capability	Fast high power charger ready for testing	Fast high power charger on market	
Policy			
Infrastructure enabling electric transport	Early implementation of electric vehicles	Electric transportation well established in central urban areas	Electric transportation well established in suburban areas nation wide
Promote electric transport and conserve bioenergy for periods without intermittent renewable power	Tax incentives and subsidies for use of electric and bioenergy for transport	Legislative framework established for mix of electric and bioenergy	

13.5 Recommendations

- Politicians communicate a clear policy target for implementation of electric vehicles for private and public transport and set a good example themselves
- Increase basic and applied research programmes in storage technologies
- Establish massive field test in a limited market among "technology friendly" customers to limit car sales risk for new products
- Establish back-up plan for batteries
  - second source as minimum
  - Industrial standard parts (– standards)

- Encourage a common sub-supplier network
- Establish cross system co-operation where energy suppliers and car suppliers and authorities work together to get optimal benefit of their investments.
- Establish research into new market schemes for the whole electric vehicle industry sector.

<u>Proponents</u>

- Alexandra Hayles, C-questor (Chairman)
- Kjeld Nørregaard, Danish Technological Institute (Rapporteur)
- Søren Linderoth, Risø DTU, Denmark
- Per Jørgensen Møller, Nokia & Danish Electric Car Commetee
- Karsten Hedegaard, Cowi (day 1 only)
- Tommy von Pein, 21st-cc

Target 14: Improvement of industrial waste heat utilization.

Efficiency gains in industrial heat supply from wastes should increase to savings of 3000 PJ/year by 2050 in OECD-Europe (a saving of 10 % of the total heat demand).

14.1 <u>Target description</u>

Based on the scenario cited below[7], efficiency gains in industrial heat supply can be estimated to offer the saving potential of about 3000 PJ/year by 2050 in OECD-Europe (a saving of 10 % of the total heat demand). The remaining reductions can be realized by efficiency improvements in the building environment.

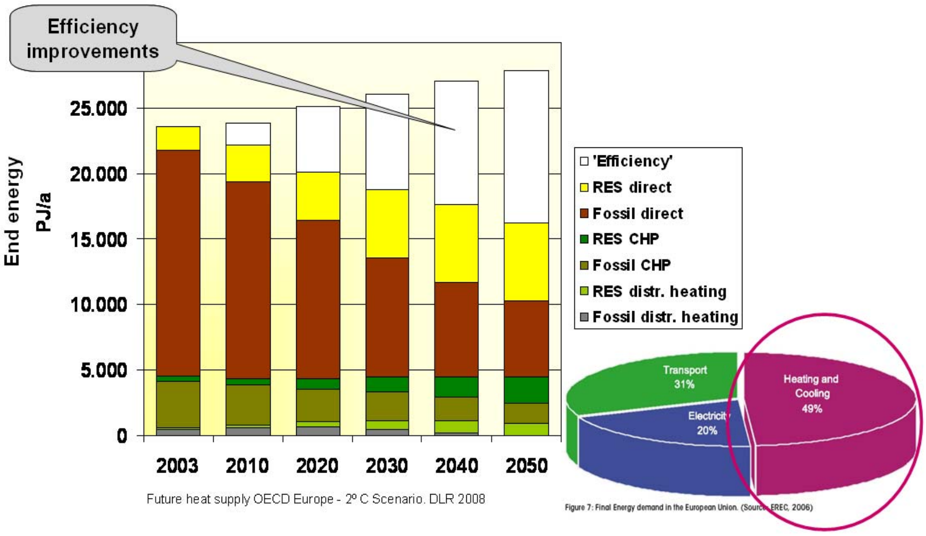

Figure 1 – Illustration of the make-up of heat supply in Europe[8]

Heat storage is a key element for improved heat management in industrial processes and is therefore essential to increase gains in industrial heat supply from wastes. It is estimated that around one-third of the total potential for efficiency improvements in industry should be realized by heat storage. The goal is to provide storage capacity of 1000 PJ per year by 2050.

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[7] Greenpeace/EREC, 2008. Energy [R]evolution 2008 – a sustainable world energy outlook. Published by Greenpeace International and the European Renewable Energy Council (EREC), www.energyblueprint.info.

[8] Left graph: Greenpeace/EREC, 2008. Energy [R]evolution 2008 – a sustainable world energy outlook. Published by Greenpeace International and the European Renewable Energy Council (EREC), www.energyblueprint.info. Right graph: European Solar Thermal Technology Platform (ESTTP): Solar Heating and Cooling for a Sustainable Energy Future in Europe, ESTTP, c/o ESTIF, www.esttp.org.

14.2 Challenges

14.2.1 Market and industry

We should provide standard solutions for waste heat utilization.

This could include: steam storage at 100-300 °C, solid media storage below 400 °C), Phase Change Material (PCM) storage for steam applications at 100-400 °C and Thermo Chemical Material (TCM) storage at 100-1000 °C.

14.2.2 Research and education

- **Development of novel storage technologies including novel materials and systems.**

  E.g. development of Phase Change Material (PCM) storage and Thermo Chemical Material (TCM) storage for elevated temperatures.

14.2.3 Policy

- **Create incentives for industrial waste heat utilization.**
- **Define R&D programmes to stimulate research in new storage materials and techniques.**

14.3 Actions and recommendations

14.3.1 Market and Industry

Some actions appear in more than one of the three sectors, indicating that the tasks require action from more than one participating sector.

Action 1: Quantifying the industrial waste heat potential.
Action 2: Qualifying the industrial waste heat potential (heat storage demand, temperature levels, materials involved).
Action 5: Development of standard solutions and products.

14.3.2 Research and education

Action 1: Quantifying the industrial waste heat potential
Action 2: Qualifying the industrial waste heat potential (heat storage demand, temperature levels, materials involved)
Action 3: Development of novel heat storage technologies (elevated temperatures, higher energy densities, higher power densities, lower costs)
Action 4: Development of novel waste heat utilization technologies (organic Rankine cycle, thermoelectric generator, heat pump, etc.)

14.3.3 Policy

Action 1: Quantifying the industrial waste heat potential
Action 3: Create research programmes for the development of novel heat storage technologies (elevated temperatures, higher energy densities, higher power densities, lower costs)
Action 4: Create research programmes for the development of novel waste heat utilization technologies (organic Rankine cycle, thermoelectric generator, heat pump, etc.)
Action 6: Encourage consulting to the industrial consumer, make energy plans and audits obligatory
Action 7: Introduce political incentives (subsidies, taxes) to stimulate market development

14.4 Road map

Actions	2010-2015	2016-2025	2026-2035
Industry (consumer/supplier)			
A1: Quantify waste heat potential	X		
A2: Qualify waste heat potential	X		
A5: Product development		X	X
Research			
A1: Quantify waste heat potential	X		
A2: Qualify waste heat potential	X		
A3+A4: Technology development	X	X	X
Policy			
A1: Quantify waste heat potential	X		
A3+A4: Create research programmes	X	X	X
A6: Customer consulting and audit		X	X
A7: Stimulate market development		X	X

14.5 Proponents

- Camilo C. M. Rindt, Eindhoven University of Technology, Netherlands (Chairman)
- Frederik Berg Nygaard, Risø DTU, Denmark (Rapporteur)
- Søren Vestesen, Danvest Energy A/S, Denmark
- Allan Schrøder Pedersen, Risø DTU, Denmark
- Stefan Zunft, German Aerospace Center (DLR), Germany

Target 15: Establish sufficient storage capacity for electricity to facilitate the phasing out of fossil fuel in the electricity system.

15.1 Target description

The unspecified target reflects that the amount of grid energy (electricity) storage needed in the system depends on both the amount and the nature of the installed renewable energy sources.

15.2 Challenges

15.2.1 Market and industry

- Establish codes and standards for grids and storage functionalities
- Integrate storage systems in power market system
- Assess regional energy storage needs
- Match technological and economically feasible options to geographical needs for energy storage
- Predict fossil fuel costs

15.2.2 Research

Electricity system:
- demonstrate maturity of storage technologies
- define required functionalities of the electricity system
- enable integration of storage systems into electricity grid
- quantify electricity fluctuation and reserve power needs
- monitor and control high number distributed resources

Technology:
- improve modelling of electricity storage systems including grid interconnect
- increase economical viability by Total Life Cycle Costs (TLCC) analysis
- Carry out life time assessments, demonstration and prediction

Financial:
- Establish appropriate assumptions for Net Present Value (NPV), Return On Investment (ROI), and Total Life Cycle Costs (TLCC) calculations
- Valuation of storage and market design

15.2.3 Policy

- Establish interconnections to allow for international trading of electricity
- Establish regulations to consider electricity storage as grid service (not as consumer)
- Establish incentives for increasing renewable energy (RE) and electricity storage, and to reduce use of fossil fuels (FF)

- Establish markets for energy and ancillary services, also open for small-scale, distributed resources

15.3 Actions and recommendations

Action 1: Demonstrate an overall package for integration of renewable energy (RE) integration with storage, smart grid operation, market incentives
Action 2: Increase funding for research into energy storage technology and system integration
Action 3: Improve tools to control fossil fuel costs
Action 4: Improve electricity markets (energy and ancillary services)
Action 5: Establish interconnections

15.4 Road map

Actions	2010-2015	2016-2025	2026-2035
Industry / market			
Demonstrations	X	X	X
Establish grid interconnections	X	X	
Research			
Storage technologies	X	X	X
System integration	X	X	X
Policy			
Research funding	X	X	X
Improve electricity markets	X		
Tools for fossil fuel cost control	X		

Proponents

- Kai Heussen, DTU Elektro, Denmark (Chairperson)
- Claus Ekman, Risø DTU, Denmark (Rapporteur)
- Kevin Harrison, NREL, USA
- Kristina Juelsgaard, SEAS-NVE, Denmark
- Niels Falsig Pedersen, DTU Elektro, Denmark
- Karsten Hedegaard, COWI, Denmark
- Niels Schrøder, RUC, Denmark
- Lars Fodstad, Statkraft Energy AS, Norway
- Henrik Bindner, Risø DTU, Denmark
- Jillis Raadschelders, KEMA, The Netherlands

FINAL PROGRAMME

14 JANUARY 2009

08:00	BUS DEPARTURE FROM RADISSON SAS HOTEL TO DTU IN LYNGBY
08:00 – 09:00	REGISTRATION AND COFFEE Where: Anker Engelunds Vej, Building 101, Entrance F, Oticon Hall
09.00-10.45	WELCOME AND INTRODUCTION TO THE WORKSHOP Where: Oticon Hall – see map Henrik Bindslev, Director of Risø National Laboratory for Sustainable Energy, DTU, Denmark Raffaele Liberali, Director, Directorate "Energy", Directorate-General for Research, European Commission Tomas Kåberger, Director General, Professor, Swedish Energy Agency Knud Pedersen, Vice President, DONG Energy, Denmark
10.45-11.00	WALKING TO PARALLEL SESSION FACILITIES IN BUILDING 306
11.00-13.00	PARALLEL SESSIONS IN BUILDING 306 Invited presentations (See individual session programmes for wind, solar, bio and storage)
13.00-14.00	WALKING TO BUILDING 101, LUNCH IN SPORTS HALL, WALKING BACK TO 306
14.00-16.00	PARALLEL SESSIONS IN BUILDING 306
16.00-16.15	COFFEE BREAK
16.15-18.15	PARALLEL SESSIONS IN BUILDING 306 AND 302 Working groups
18:30 – 19:00	REFRESHMENTS BEFORE DINNER Where: Canteen, Building 101
19:00 – 21:30	DINNER IN THE DTU CANTEEN Dinner speech by Henrik Bindslev, Director of Risø National Laboratory for Sustainable Energy, DTU, Denmark
21:45	BUS DEPARTURE FOR RADISSON SAS HOTEL IN COPENHAGEN

15 JANUARY 2009

08:00	BUS DEPARTURE FROM RADISSON SAS HOTEL TO DTU IN LYNGBY
09:00 – 10:00	PARALLEL SESSIONS IN BUILDING 302 AND 306 Working groups
10:00 – 10:30	COFFEE BREAK
10:30 – 12:30	PARALLEL SESSIONS IN BUILDING 302 AND 306 Working groups
12:30 – 13:30	LUNCH Where: Sports Hall, building 101, Entrance F
13:45 – 15:30	PARALLEL SESSIONS IN BUILDING 306 Presentations and discussions in plenum of targets and roadmaps.
15:30 – 16:00	REFRESHMENTS AND COFFEE Where: Anker Engelunds Vej, Buiding 101, Entrance F, Oticon Hall
16:00 – 18:00	PRESENTATIONS AND PANEL DISCUSSION OF SELECTED TARGETS AND ROADMAPS, BUILDING 101, ENTRANCE F, OTICON HALL Chairman: Henrik Bindslev, Director of Risø National Laboratory for Sustainable Energy, DTU, Denmark Panel: Kim Behnke, Head of Section, Energinet DK, Denmark Poul Erik Morthorst, Professor, Risø National Laboratory for Sustainable Energy, DTU, Denmark Arthouros Zervos, Professor, President, European Wind Energy Association Torben Esbensen, Esbensen Engineering, Sønderborg, Denmark

WIND POWER

14 JANUARY 2009

11.00 – 13.00 PARALLEL SESSIONS IN BUILDING 306, AUDITORIUM 36

PRESENT STATUS AND PERSPECTIVES

CHAIRMAN: PETER HJULER JENSEN

INTRODUCTION OF THE UNFCCC-CLIMATE SUMMIT (COP15)
Ministry of Climate and Energy

STRATEGY AND PLANS FOR WIND ENERGY IN CHINA
Deputy Director General Li Jungfeng, Energy Research Institute, China

PRESENT STATUS OF THE WIND ENERGY
Birger Madsen, BTM Consult, Denmark

THE GOAL WIND ENERGY GOAL FOR 2020
Professor, President, Arthouros Zervos, European Wind Energy Association

PRECONDITIONS AND ASSUMPTIONS FOR LARGE SCALE UTILISATION OF WIND ENERGY
Professor Poul-Erik Morthorst, Risø National Laboratory for Sustainable Energy, DTU, Denmark

US WIND ENERGY STRATEGY AND TECHNOLOGY OVERVIEW
Principal Engineer, Sandy Butterfield, National Renewable Energy Laboratory, US

14.00 – 16.00 PARALLEL SESSIONS IN BUILDING 306, AUDITORIUM 36

CHALLENGES AND OPPORTUNITIES

CHAIRMAN: FLEMMING RASMUSSEN

GLOBAL WIND RESOURCES AND METEOROLOGICAL CHALLENGES
Head of Division, Erik Lundtang Petersen, Risø National Laboratory for Sustainable Energy, DTU, Denmark

CAN THE INDUSTRY DELIVER?
CTO, Henrik Stiesdal, Siemens Wind Power

LARGE SCALE GRID INTEGRATION
Hannele Holttinen, VTT Finland

FUTURE WIND TURBINE TECHNOLOGY
Director, David Quarton, Garrad Hassan Group Ltd (GH), UK

BIOENERGY

14 JANUARY 2009

11.00 – 13.00 PARALLEL SESSIONS IN BUILDING 306, AUDITORIUM 31

BIOMASS RESSOURCES FOR BIOFUELS FOR TRANSPORTATION

CHAIRMAN: KIM PILEGAARD

GLOBAL SUSTAINABLE BIORESOURCES FOR BIOENERGY PRODUCTION
Dr. Edward Smeets, Utrecht University, The Netherlands

THE ROLE OF THE AGRICULTURAL SECTOR IN BIOMASS PRODUCTION
Peter Gæmelke, Landbrugsrådet, Denmark

THE ROLE OF LIGNOCELLULOSE-DERIVED BIOFUELS IN A SUSTAINABLE ENERGY PORTFOLIO
Professor Jack Saddler, University if British Columbia, Canada

THE INTEGRATED BIOMASS UTILIZATION SYSTEM (IBUS)
Charles Nielsen, Dong Energy, Denmark

14.00 – 16.00 PARALLEL SESSIONS IN BUILDING 306, AUDITORIUM 31

THERMAL GASIFICATION, BIOGAS AND SUSTAINABILITY OF BIOENERGY

CHAIRMAN: ERIK STEEN JENSEN

GASIFICATION OF BIOMASS FOR FUELS AND POWER
Suresh P. Babu, Institute Fellow, Gas Technology Institute, USA

BIOGAS PRODUCTION IN PRACTICE
Frank Rosager, Xergi, Denmark

SUSTAINABILITY OF BIOENERGY
Dr. Horst Fehrenbach, IFEU Institute Heidelberg, Germany

POLICY FOR INCREASED SHARE OF BIOENERGY
Peder Jensen, European Environment Agency, Denmark

SOLAR ENERGY

14 JANUARY 2009

11.00 – 13.00 PARALLEL SESSIONS IN BUILDING 306, AUDITORIUM 37

SOLAR THERMAL

CHAIRMAN: DR. ELSA ANDERSEN, TECHNICAL UNIVERSITY OF DENMARK

KEYNOTE SPEAKER SOLAR THERMAL
Dr. Alexander Thür, Institute for Sustainable Technologies, Austria

SOLAR THERMAL 1: SDHW SYSTEMS AND SOLAR COMBI SYSTEMS
Associate Professor, Simon Furbo, Technical University of Denmark

SOLAR THERMAL 2: SOLAR HEATING PLANTS
Ass. Professor, Jan-Olof Dalenbäck, Chalmers University, Sweden

SOLAR THERMAL 3: HEAT STORAGE
Dr. Ing., Harald Drück, ITW, Stuttgart University, Germany

SOLAR THERMAL 4: SOLAR HEATING MARKET
Jes Donneborg, Arcon Solvarme A/S, Denmark

14.00 – 16.00 PARALLEL SESSIONS IN BUILDING 306, AUDITORIUM 37

PHOTOVOLTAICS

CHAIRMAN: DR. PETER SOMMER LARSEN, RISØ NATIONAL LABORATORY FOR SUSTAINABLE ENERGY, DTU, DENMARK

KEYNOTE SPEAKER PHOTOVOLTAICS
Director, Peter Ahm, PA Energy, Denmark

POLYMER SOLAR CELLS
Dr. Frederik C. Krebs, Risø DTU National Laboratory for Sustainable Energy, Technical University of Denmark

HIGH-EFFICIENCY MULTIJUNCTION SOLAR CELLS FOR CONCENTRATOR PV APPLICATIONS
Dr. Giovanni Flamand, IMEC, Belgium

COMPETITIVE CRYSTALLINE SILICON PHOTOVOLTAIC TECHNOLOGY
Dr. Jan H. Bultman, Energy Research Centre of the Netherlands (ECN), The Netherlands

ENERGY STORAGE

14 JANUARY 2009

11.00 – 13.00 PARALLEL SESSIONS IN BUILDING 306, AUDITORIUM 38

STORAGE

CHAIRMAN: ALLAN SCHRØDER PEDERSEN

THE FUTURE NEED FOR ENERGY STORAGE FOR TRANSPORT
Business Development Manager, Ulf Hafseld, StatoilHydro ASA, Norway

THE FUTURE NEED FOR ENERGY STORAGE FOR BALANCING MISMATCH BETWEEN DEMAND AND SUSTAINABLE PRODUCTION OF ELECTRICITY
Head of Section, Kim Behnke, Energinet.dk, Denmark

14.00 – 16.00 PARALLEL SESSIONS IN BUILDING 306, AUDITORIUM 38

TECHNOLOGIES

CHAIRMAN: AKSEL HAUGE PEDERSEN

BATTERIES FOR TRANSPORT
Senior Research Manager, Per Jørgensen Møller, Nokia Danmark A/S

BATTERIES FOR STATIONARY APPLICATIONS
Senior Consultant, Jillis Raadschelders, KEMA Consulting, The Netherlands

COMPRESSED AIR ENERGY STORAGE
Head of Section, Associate Professor, Brian Elmegaard, DTU Mechanical Engineering, Technical University of Denmark

PUMPED HYDRO
Senior Vice President, Lars Audun Fodstad, Statkraft AS, Norway

ELECTROLYSIS
Dr. Kevin Harrison, National Renewable Energy Laboratory, Colorado, USA

HEAT STORAGE
Dr.-Ing. Stefan Zunft, German Aerospace Center, Stuttgart, Germany

Risø DTU is the National Laboratory for Sustainable Energy. Our research focuses on development of energy technologies and systems with minimal effect on climate, and it contributes to innovation, education and policy. Risø has large experimental facilities and interdisciplinary research environments, and includes the national centre for nuclear technologies.

This report is part of a series of workshops and conferences arranged as a part of DTU Cimate Change Technology, a research programme run by the Technical University of Denmark.

DTU Climate Change Technologies aims to take scientific research, present it to key players in the fields of energy and climate changes to produce new technologies and processes. The goal is to reduce CO_2 emissions and support industrial production and welfare in adapting to climate change. Read more at dtu.dk/subsites/klima/English.aspx

Workshops

Sustainable Buildings - 19 June 2008
Future Energy Systems - 19 - 20 November 2008
Sustainable Energies - 14 - 15 January 2009
Animal Health and Food Safety - March 2009
Transport - renewable energy in the transport sector and planning - 17 - 18 March 2009
Climate Changes and Ecosystem Productivity - May 2009
Combustion, Carbon Capture and Storage - 27 - 28 May 2009
InfraStructure and Climate Changes - 1 September 2009

Research conferences

Changes of the Greenland Cryosphere - 25 - 28 August 2009
Risø International Energy Conference - 14 - 16 September 2009

Final round-up forum

High-level Conference - 17 September 2009

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